Naval Aerospace Medical Research Laboratory

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Naval Aerospace Medical Research Laboratory
51 Hovey Road
Pensacola, Florida 32508-1046

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L. H. FRANK, CAPT, MSC USN
Commanding Officer

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ABSTRACT

The Secretary of Defense directed the military services to allow women to fly all aircraft engaged in combat missions. The current inventory of naval aircraft was designed to accommodate the general physical characteristics of the male population based on information that is over 20 years old. Anthropometric standards have been used for a number of years to certify that individuals entering naval aviation can fit into assigned aircraft. However, there are no established strength standards to assess whether aviation candidates are capable of operating manual foot and hand controls. This study was done to determine current muscular strength and anthropometric characteristics of male and female aviation candidates. Volunteer subjects included 458 male and 152 female naval aviation students and Naval Academy Midshipmen. Cybex muscle testing equipment was used to measure the strength and endurance of muscles in the arm, shoulder, and leg. Fourteen different anthropometric measurements were made. Compared to males entering naval aviation, female candidates were weaker than their male counterparts when measuring both upper and lower body limb strength. Anthropometry indicated obvious differences in body size with men generally larger than women in most measurements. The data obtained in this study can be used to develop occupational strength standards for modern aviation, modify aircraft cockpits, and redesign aviation life support equipment. These results may help the Navy in preparing candidates for aviation and foster confidence in the assignment of aircraft.

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INTRODUCTION

A recent memorandum (1) from the Assistant Secretary of the Navy stated: "We are faced with a multitude of challenges, as we strive to integrate women into Navy and Marine Corps aircraft. Equipment and cockpit designs are based on male sizing. This severely limits the pool of eligible female pilots. New pipeline training aircraft (Joint Primary Aircraft Training System [JPATS] and T-45) will accommodate a much wider range of eligible females. As our flight experience expands, we are identifying additional female concerns and issues. The following is a list of just some of these: safety and survivability; specific physiological and psychological needs; clothing and protective equipment; cockpit fit and compatibility/assignment potential in fleet aircraft. These issues are not Navy and Marine Corps unique but shared by the other services."

The National Academy of Sciences concurred with these concerns in the Defense Women's Health Research Program (DWHRP) Guidance Report. As a result, the Bureau of Naval Personnel (BUPERS) requested that the Bureau of Medicine and Surgery (BUMED) address these issues and that the Naval Aerospace Medical Research Laboratory (NAMRL) work with the Naval Aviation Schools Command (NASC) to develop a plan of action for research to answer specific questions about the problems associated with women flying naval aircraft.

Routine occupational tasks connected with flying are not considered physically strenuous. However, physical strength and endurance are required in certain situations to perform routine and emergency tasks successfully (e.g., high-G maneuvers, manual landing gear extension, ejection seat actuation, manual opening and closing of hatches and canopies) in all naval aircraft. Currently, the only physical strength/endurance tests utilized in naval aviation are the Navy Physical Readiness Test (PRT) (2) and specific physical training activities (e.g., obstacle course) in the NASC physical training curriculum. Although both programs are gender- and age-normed, they have never been validated against specific aviation occupational strength requirements, and they are generally outdated. Additionally, current physical testing does not predict success for pilots and naval flight officers (NFOs) in accomplishing specific occupational aviation tasks. This creates a safety concern as a greater number of individuals enter (combat) aviation who may be smaller and weaker than the average aviation candidate.

The purpose of this report was to identify and quantify the muscular strength and endurance attributes needed to successfully perform the manual tasks of flying naval aircraft. Because physical size and muscular strength are directly related, anthropometric characteristics were also important to evaluate the muscular traits obtained in this work. These measurements were essential as precursors to the development of strength standards for aviators. From personal communications with the Naval Test Pilots School, Patuxent River, Maryland, we learned that strength and anthropometry are directly related to the ability to perform manual aviation tasks and physically fit into aircraft. Therefore, the approach in this work was to measure both strength and anthropometry in naval aviation candidates to identify existing measurements and distinguish differences between the men and women.

Presently, there are no standards for strength or endurance for individuals entering naval aviation. Methods to achieve optimal physical fitness as it pertains to aviation duties have not been examined previously. Likewise, nothing has been done in recent years to establish gender-neutral strength standards for aviators. On the other hand, anthropometric standards have been used to screen aviation candidates for cockpit fit for many years. However, the last anthropometric data base from the naval aviation population was completed in 1964 and was taken entirely from male subjects. Therefore, the rationale for developing the strength and anthropometric data bases was the lack of a strength data base and antiquated anthropometric standards for naval aviation.

Previous studies have shown strength differences between men and women especially in upper body muscles (3-8). In a review of the literature, Laubach (9) reported that women ranged from 35 to 79% of men's upper extremity strength, averaging 55.8%. Teves, et al. (10) found, when normalized for body weight, females were 75% as strong as males on isometric measures. Robertson (11) reported the greatest strength differences between men and women on upper torso dynamic strength tests, push-up, pull-up, and bent arm hang where women's means were 10, 5, and 23%, respectively of men's scores. All of these studies concluded that strength differences between men and women were due to smaller muscle mass in women.

Smaller muscle masses were also seen in men of smaller stature as well as women. Therefore, strength screening standards should appropriately address individual characteristics without reference to gender. McDaniel found that men were stronger than women when measured on 10 different aircraft tasks (12). However, his study concluded that the correlation between strength and size was not significant and that cockpit evaluators should select subjects for their strength characteristics, not gender. Whether or not size is a determining factor , enough evidence indicates a need for task-specific, gender-neutral strength testing in aviation.

This work was part of a larger project designed to provide several products to naval aviation to enhance physical training, anthropometric standards, and aviation task performance. An aviation strength screening device was constructed to allow NASC to identify strength deficiencies in aviation candidates. Additionally, an aviation task strength training program to rectify deficiencies in candidates was designed and validated. This report describes the initial efforts in quantifying and analyzing the data used to develop these products.

METHODS AND MATERIALS

Initially, experienced naval aviators were surveyed to identify critical manual tasks used in flying naval aircraft. The muscular forces required to perform these tasks in the most extreme situations were determined. These tasks were then analyzed for specific muscular involvement. Three different important movements were singled out for testing. Male ($n = 458$) and female ($n = 152$) student naval aviators, student NFOs, and U.S. Naval Academy First and Second Class Midshipmen were tested on a muscular strength and endurance battery and anthropometric measurement series. Power calculations indicated that 150 female subjects were needed for valid comparisons with the male subjects. Muscular strength and endurance were measured with a Cybex 6000 muscle testing device. Three major muscle groups in the body were tested because of their involvement in performing critical occupational tasks in aviation: the large muscles of the upper leg that extend and flex the knee (quadriceps and hamstrings), the muscles acting on the shoulder joint to cause rotation, and the elbow extensors and flexors (biceps and triceps).

The Cybex device was configured to measure isokinetic concentric/concentric muscular force. For strength assessment, the speed of movement was set at 60°/s and three to four maximal-exertion repetitions were performed. Following each strength set and a short rest period of at least 20 s, a set of 20 maximal-exertion repetitions at 180-240°/s were done for endurance assessment on the same muscle group. Only the right side of the body was tested to reduce the time of participation and maintain uniformity among subjects. Strength and endurance variables measured included peak torque, torque acceleration energy, average power, and total work as defined below:

<u>Total Work</u> - the total amount of work of all of the repetitions in a set.

<u>Average Power</u> - the total work divided by the time it takes to perform the work.

<u>Peak Torque</u> - the greatest torque generated by a muscle contracting through a range of motion.

<u>Torque Acceleration Energy</u> - the total work in the first ⅛ of a second of a contraction through a range of motion.

Grip strength in both hands was measured with a hand-grip dynamometer. The average of three trials was recorded. All of the subjects were given verbal encouragement by the operators during the strength tests to perform their best.

Because of their importance in relating to proper cockpit fit, 14 body dimensions and body weight were measured: weight, stature, thumbtip reach, bideltoid breadth, sitting height, sitting eye height, sitting acromial height, abdominal extension depth, sitting hip breadth, thigh circumference, thigh clearance, buttock-knee length, sitting knee height, and functional leg length. The different anthropometric measurements/variables are defined below:

Abdominal Extension Depth - the greatest horizontal distance between the anterior point of the abdomen and the back at the same level in the anthropometric sitting position.

Acromial Height, Sitting - the vertical distance between the sitting surface and the tip of the shoulder in the anthropometric sitting position.

Bideltoid Breadth - the greatest horizontal distance between the outside edges of the deltoid muscles on the upper arms in the anthropometric sitting position.

Buttock-Knee Length - the horizontal distance between the back of the buttock and the front of the knee in the anthropometric sitting position.

Eye Height, Sitting - the vertical distance between the sitting surface and the outer corner of the eye in the anthropometric sitting position.

Functional Leg Length - with the leg fully extended, the straight-line distance between the footrest surface and the back surface of the body in line with the tip of the trochanter.

Height, Sitting - the vertical distance between the sitting surface and the top of the head.

Hip Breadth, Sitting - the most lateral points on the hips or thighs, whichever are greater.

Knee Height, Sitting - the vertical distance between the footrest surface and the top of the knee in the anthropometric sitting position.

Stature - the vertical distance between the standing surface and the top of the head.

Thigh Circumference - circumference of the thigh at its juncture with the buttock perpendicular to thigh's long axis.

Thigh Clearance - the vertical distance between the sitting surface and the highest point on the top of the thigh.

Thumbtip Reach - standing with shoulders against a wall, the horizontal distance between the back wall and the tip of the thumb when the arm is stretched forward horizontally.

All measurements were made according to the procedure described by Gordon, et al. (13) using a GPM Anthropometer (Seritex, Inc.). Skinfold measurements for body fat assessment were included in the anthropometric analysis. The sum of three skinfolds using a Lange Skinfold Caliper (Cambridge Scientific Industries, Inc.) was used to determine body composition and to estimate body fat (14). Men's skinfold sites were the chest, abdomen, and the thigh. The women's skinfold sites were the triceps, the suprailiac, and thigh.

Descriptive statistics for the strength, endurance, and anthropometric data were determined for both gender groups. Additionally, the differences between the means of the males and females were determined using analysis of variance (ANOVA). When significant differences were found, further analysis was done for individual comparisons with a Tukey-Kramer post hoc test. Correlational analysis was done to determine colinearity or the amount of variance accounted for by each variable in the model. Statistical significance was set at $p < 0.05$.

RESULTS

The muscular strength measurements acquired on all candidates are shown in Table 1. Male candidates were significantly stronger than female candidates on all measurements. The muscular endurance of the males was similarly greater than the endurance of the females on all measurements (Table 2). The strength and endurance

measurements of the female subjects were compared to those of the males as a mathematical ratio (Table 3). The percentages for knee strength were 64 and 66% for flexion and extension, respectively. Knee endurance ratios were similar. Elbow extension ratios (65%) were greater than flexion percentages (56%) for strength. Elbow endurance comparisons were similar but 9 and 10% less than strength in flexion and extension. Shoulder strength and endurance ratios for flexion and extension were all similar and ranged from 56 to 61%.

Anthropometric measurements of both female and male subjects are summarized in Table 4. All but two of the measurements were significantly larger for the males. Sitting hip breadth of the female subjects was greater than that of the male subjects. There was no significant difference between men and women in thigh circumference.

The relationships among strength and anthropometric variables for the men are shown in Tables 5-7. All of the correlations were positive, but none was significant or strongly related. Body weight showed a moderate positive correlation with peak torque on knee flexion with $r = 0.55$. Likewise, all of the relationships between strength and anthropometry for female candidates were low to moderate and positive (Tables 8-10). The greatest correlation was between peak torque on knee extension and body weight, $r = 0.69$.

DISCUSSION

The purpose of this work was to determine the strength and anthropometric characteristics of the current naval aviation candidate population. Performance requirements were identified that were representative of movements that demanded instantaneous muscular strength, sustained strength, and muscular endurance for routine and emergency operations in all naval aircraft. Strength and anthropometric data on 610 male and female aviation candidates were gathered and analyzed.

In general, our observations of stronger men, when compared to women, were consistent with other reports (3,5-9). Both upper and lower body strength and endurance measurements in the female subjects were 50-66% that of their male counterparts. These findings are not unusual even in fit women since strength is related to many different anatomical and physiological variables that are different between the sexes.

This work may lead to the development of gender-neutral, occupational strength standards that would identify individuals incapable of meeting specific strength performance requirements to conduct flight operations safely as pilots and NFOs. The results may enable the Navy to open aviation to a wider anthropometric segment of the general population. Some candidates may be restricted from flying certain aircraft because of strength/safety concerns, but the restrictions will be based on scientifically derived standards that will be applied equally to all aviation applicants. The anthropometry data may be used to redesign aircraft cockpit spaces, resize aviation clothing, and update standards for fit into naval aircraft. Results from this study can be used by the U.S. Army, the U.S. Air Force, and many foreign countries that fly American-made aircraft. Other potential benefits of this project may include the development of a strength test battery for screening Naval Academy and Reserve Officers' Training Corps Midshipmen applying for flight training and a physical strength enhancement program to enable aviation candidates to meet or exceed the strength standards.

CONCLUSIONS

Women entering naval aviation are representative of the general female college population in strength when compared to their male counterparts. They are weaker in both upper and lower body musculature. Based on the forces required to operate the controls of naval aircraft, these data prompt questions on the ability of women to proficiently operate naval aircraft under any circumstance. Further work is required to determine valid and reliable aviation occupational standards to identify deficiencies in aviators or, possibly, aid in the selection process for aircraft type upon assignment. Other occupational standards (e.g., crew station accommodation, anthropometric compatibility, egress system safety considerations) integrate with strength and endurance standards and need to be examined in additional research programs.

RECOMMENDATIONS

1. Continue development of an aviation task-related muscular strength and endurance conditioning program.

2. Expand the current anthropometric data base of aviation candidates to provide information for resizing aviation clothing and life-support equipment.

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Other Related NAMRL Publications

Luzier, A.R., Erickson, D.G., McKay, J.R., Baisden, A.G., and Pokorski, T.L. "Occupational Strength Testing Related to Gender-neutral Issues in Naval Aviation: A Selected Bibliography." *Naval Aerospace Medical Research Laboratory*, Pensacola, FL, Monograph 47, 1995.

Table 1. Means (*X*) and Standard Deviations (*SD*) of Muscular Strength Variables of Male ($n = 458$) and Female ($n = 152$) Aviation Candidates.

Variables	Male		Female		*t* value
Knee					
Flexion					
Peak torque (ft lbs)	99.62	17.84	64.06	11.94	22.19*
TAE (ft lbs)	7.52	1.79	4.71	1.11	18.17
Extension					
Peak torque (ft lbs)	172.12	30.47	113.20	20.47	22.23*
TAE (ft lbs)	11.68	2.62	7.03	1.52	20.67*
Elbow					
Flexion					
Peak torque (ft lbs)	41.01	7.82	22.78	4.89	27.38*
TAE (ft lbs)	2.48	0.85	1.12	0.42	19.20*
Extension					
Peak torque (ft lbs)	44.34	9.34	28.74	6.42	23.03*
TAE (ft lbs)					
Shoulder					
Flexion					
Peak torque (ft lbs)	26.09	5.87	15.94	3.90	20.13*
TAE (ft lbs)	2.65	0.63	1.48	0.41	21.86*
Extension					
Peak torque (ft lbs)	42.75	9.01	25.81	5.45	22.13*
TAE (ft lbs)	3.69	0.97	2.18	0.59	19.58*
Grip Strength					
Right (kg)	52.01	6.96	36.39	5.19	11.63*
Left (kg)	49.57	6.87	34.01	5.13	11.32*

* $P < .05$
TAE = Torque Acceleration Energy

Table 2. Means (X) and Standard Deviations (SD) of Muscular Endurance Variables of Male (n = 458) and Female (n = 152) Aviation Candidates.

Variables	Male		Female		t value
Knee					
Flexion					
Total work (ft lbs)	80.79	16.31	52.82	12.11	19.44*
Avg power (W)	203.13	41.06	136.06	29.47	18.61*
Extension					
Total work (ft lbs)	123.11	23.02	78.03	16.32	2.35*
Avg power (W)	303.09	64.94	196.13	41.41	19.06*
Elbow					
Flexion					
Total work (ft lbs)	38.35	9.56	17.14	5.60	26.22*
Avg power (W)	90.19	24.18	38.76	15.44	25.25*
Extension					
Total work (ft lbs)	47.13	9.46	25.88	6.33	25.14*
Avg power (W)	109.41	23.76	61.10	15.44	23.75*
Shoulder					
Flexion					
Total work (ft lbs)	25.32	6.69	13.86	14.43	19.95*
Avg power (W)	53.93	14.86	30.81	10.01	18.08*
Extension					
Total work (ft lbs)	480.19	9.79	28.48	6.33	23.51*
Avg power (W)	101.19	23.24	62.89	14.73	19.30*

* $P < .05$

Table 3. Percentage (%) Comparisons of Female (n = 152) to Male (n = 458) Muscular Strength and Endurance Variables Measured with a Cybex 6000 Dynamometer.

Percentges (%)	Strength		Endurance	
	Peak Torque (ft lbs)	TAE (ft lbs)	Total work (ft lbs)	Ave power (ft lbs)
Knee				
Flexion	64	63	65	67
Extension	66	60	63	64
Elbow				
Flexion	56	45	45	43
Extension	65	58	55	56
Shoulder				
Flexion	61	56	56	57
Extension	60	58	58	62

*$P < .05$

Table 4. Means (X) and Standard Deviations (SD) of Anthropometric Variables of Male (n = 458) and Female (n = 152) Aviation Candidates.

Variables	Male		Female		X Difference	Total (n = 610)	
Weight	79.33	9.52	64.60	8.27	18.18*	75.71	1.19
Stature	179.37	6.62	67.01	6.09	21.21*	176.29	8.41
Thumbtip reach	82.63	4.35	75.11	3.86	17.40*	79.93	5.52
Bideltoid breadth	49.55	2.70	44.97	2.39	19.77*	48.41	3.29
Abdominal extension depth	22.80	72.09	20.17	2.05	14.00*	22.19	2.39
Hip breadth, sitting	36.15	2.36	38.01	2.69	-7.61*	36.61	2.57
Height, sitting	93.13	3.39	87.73	2.99	18.63*	91.78	4.04
Eye height, sitting	80.98	3.09	76.02	2.95	17.74*	79.74	3.73
Acromial height, sitting	60.75	2.95	57.47	2.76	12.50*	59.93	3.23
Thigh circumference	59.76	4.31	59.15	4.09	1.55	59.61	4.26
Thigh clearance	17.32	1.18	15.98	1.13	12.45*	16.99	1.30
Buttock-knee length	62.54	2.87	59.18	2.78	12.78*	16.71	3.20
Knee height, sitting	55.86	2.65	51.33	2.76	17.64*	54.74	3.31
Functional leg length	109.93	5.22	102.37	4.88	16.23*	108.06	6.08
Body fat	13.32	4.48	22.48	4.44	37.61*	5.69	6.01

* $P < .05$

All measures are in millimeters except weight which is in kilograms and body fat in percentage.

Table 5. Correlation Coefficients (r) for Knee Strength and Anthropometry of Male (n = 58) Aviation Candidates.

Variables	Peak torque		TAE		Total work		Average power	
	Flex	Ext	Flex	Ext	Flex	Ext	Flex	Ext
Weight	0.55	0.54	0.40	0.48	0.43	0.50	0.41	0.46
Thumbtip reach	0.38	0.31	0.26	0.29	0.36	0.31	0.36	0.34
Thigh circumference	0.38	0.42	0.28	0.38	0.27	0.39	0.24	0.36
Bideltoid breadth	0.41	0.41	0.31	0.36	0.30	0.38	0.27	0.34
Hip breadth	0.30	0.33	0.24	0.28	0.19	0.28	0.18	0.26
Abdominal depth	0.21	0.27	0.13	0.23	0.15	0.25	0.14	0.23
Height	0.41	0.31	0.29	0.27	0.36	0.36	0.33	0.29
Sitting height	0.30	0.19	0.26	0.18	0.25	0.24	0.22	0.18
Eye height	0.28	0.16	0.26	0.15	0.22	0.21	0.19	0.16
Acromial height	0.25	0.12	0.23	0.11	0.18	0.17	0.16	0.15
Thigh clearance	0.42	0.47	0.29	0.41	0.34	0.47	0.31	0.41
Buttock-knee length	0.39	0.37	0.25	0.30	0.33	0.37	0.31	0.32
Knee height	0.44	0.37	0.29	0.32	0.37	0.38	0.36	0.32
Leg length	0.43	0.35	0.27	0.30	0.36	0.38	0.34	0.32

* $P < .05$

Table 6. Correlation Coefficients (r) for Shoulder Strength and Anthropometry of Male (n = 458) Aviation Candidates.

Variables	Peak torque		TAE		Total work		Average power	
	Flex	Ext	Flex	Ext	Flex	Ext	Flex	Ext
Weight	0.40	0.45	0.46	0.48	0.21	0.33	0.24	0.35
Thumbtip reach	0.18	0.21	0.25	0.29	0.12	0.16	0.14	0.17
Thigh circumference	0.30	0.35	0.31	0.36	0.14	0.22	0.17	0.26
Bideltoid breadth	0.36	0.42	0.40	0.44	0.21	0.32	0.25	0.37
Hip breadth	0.19	0.25	0.24	0.29	0.05	0.12	0.10	0.17
Abdominal depth	0.20	0.23	0.19	0.21	0.09	0.14	0.15	0.22
Height	0.10	0.10	0.25	0.22	0.04	0.15	0.02	0.09
Sitting height	0.13	0.13	0.26	0.24	0.07	0.17	0.06	0.12
Eye height	0.10	0.10	0.23	0.22	0.06	0.15	0.05	0.10
Acromial height	0.11	0.10	0.21	0.20	0.04	0.10	0.05	0.07
Thigh clearance	0.31	0.35	0.31	0.35	0.17	0.23	0.19	0.23
Buttock-knee length	0.12	0.13	0.22	0.20	0.04	0.14	0.02	0.11
Knee height	0.11	0.11	0.23	0.22	0.04	0.15	0.03	0.12
Leg length	0.10	0.12	0.21	0.21	0.02	0.14	0.01	0.10

Table 7. Correlation Coefficients (r) for Elbow Strength and Anthropometry of Male (n = 458) Aviation Candidates.

Variables	Peak torque		TAE		Total work		Average power	
	Flex	Ext	Flex	Ext	Flex	Ext	Flex	Ext
Weight	0.54	0.46	0.46	0.49	0.47	0.45	0.46	0.43
Thumbtip reach	0.31	0.23	0.19	0.24	0.24	0.25	0.24	0.24
Thigh circumference	0.36	0.29	0.36	0.37	0.34	0.32	0.33	0.29
Bideltoid breadth	0.46	0.41	0.40	0.42	0.42	0.40	0.43	0.38
Hip breadth	0.27	0.25	0.27	0.29	0.22	0.22	0.23	0.23
Abdominal depth	0.26	0.24	0.22	0.28	0.19	0.19	0.23	0.22
Height	0.30	0.24	0.17	0.17	0.22	0.23	0.19	0.21
Sitting height	0.17	0.16	0.14	0.14	0.14	0.15	0.12	0.14
Eye height	0.15	0.14	0.12	0.12	0.11	0.13	0.10	0.12
Acromial height	0.12	0.14	0.10	0.13	0.08	0.08	0.08	0.10
Thigh clearance	0.36	0.27	0.30	0.35	0.33	0.31	0.32	0.27
Buttock-knee length	0.32	0.23	0.18	0.19	0.23	0.20	0.22	0.18
Knee height	0.33	0.27	0.19	0.19	0.25	0.25	0.23	0.22
Leg length	0.34	0.25	0.19	0.19	0.27	0.27	0.24	0.23

Table 8. Correlation Coefficients (r) for Knee Strength and Anthropometry of Female (n = 152) Aviation Candidates.

Variables	Peak torque		TAE		Total work		Average power	
	Flex	Ext	Flex	Ext	Flex	Ext	Flex	Ext
Weight	0.56	0.69	0.40	0.53	0.52	0.61	0.52	0.62
Thumbtip reach	0.40	0.54	0.26	0.37	0.39	0.45	0.39	0.39
Thigh circumference	0.45	0.52	0.32	0.45	0.41	0.49	0.41	0.49
Bideltoid breadth	0.35	0.49	0.25	0.46	0.35	0.48	0.35	0.49
Hip breadth	0.26	0.31	0.19	0.24	0.21	0.30	0.19	0.33
Abdominal depth	0.33	0.40	0.27	0.32	0.27	0.34	0.29	0.38
Height	0.43	0.57	0.31	0.39	0.44	0.55	0.41	0.48
Sitting height	0.26	0.35	0.17	0.28	0.23	0.31	0.25	0.32
Eye height	0.27	0.36	0.16	0.27	0.23	0.31	0.24	0.32
Acromial height	0.20	0.32	0.09	0.21	0.18	0.28	0.17	0.29
Thigh clearance	0.38	0.54	0.23	0.44	0.41	0.48	0.41	0.46
Buttock-knee length	0.45	0.58	0.38	0.42	0.45	0.56	0.41	0.48
Knee height	0.34	0.55	0.25	0.39	0.41	0.52	0.37	0.42
Leg length	0.47	0.64	0.35	0.44	0.47	0.57	0.44	0.50

Table 9. Correlation Coefficients (r) for Shoulder Strength and Anthropometry of Female (n = 152) Aviation Candidates.

Variables	Peak torque		TAE		Total work		Average power	
	Flex	Ext	Flex	Ext	Flex	Ext	Flex	Ext
Weight	0.46	0.54	0.49	0.46	0.39	0.46	0.42	0.50
Thumbtip reach	0.24	0.24	0.32	0.27	0.32	0.41	0.22	0.34
Thigh circumference	0.34	0.38	0.35	0.29	0.25	0.32	0.25	0.33
Bideltoid breadth	0.39	0.40	0.41	0.33	0.28	0.25	0.34	0.35
Hip breadth	0.14	0.25	0.18	0.18	0.10	0.17	0.13	0.20
Abdominal depth	0.28	0.33	0.25	0.25	0.23	0.22	0.30	0.27
Height	0.28	0.30	0.37	0.32	0.33	0.40	0.26	0.33
Sitting height	0.25	0.29	0.33	0.30	0.27	0.32	0.25	0.29
Eye height	0.26	0.29	0.34	0.31	0.26	0.30	0.25	0.30
Acromial height	0.19	0.19	0.22	0.18	0.16	0.15	0.16	0.14
Thigh clearance	0.39	0.38	0.40	0.32	0.32	0.33	0.35	0.38
Buttock-knee length	0.32	0.29	0.35	0.26	0.32	0.34	0.28	0.27
Knee height	0.19	0.19	0.27	0.20	0.25	0.31	0.18	0.25
Leg length	0.28	0.28	0.31	0.24	0.31	0.38	0.24	0.30

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L. G. Meyer, T. L. Pokorski, B.E. Ortel, J. L. Saxton, and P. D. Collyer

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Naval Aerospace Medical Research Laboratory
51 Hovey Road
Pensacola, FL 32508-1046

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13. ABSTRACT *(Maximum 200 words)*
The Secretary of Defense directed the military services to allow women to fly all aircraft engaged in combat missions. The current inventory of naval aircraft was designed to accommodate the general physical characteristics of the male population based on information that is over 20 years old. Anthropometric standards have been used for a number of years to certify that individuals entering naval aviation can fit into assigned aircraft. However, there are no established strength standards to assess whether aviation candidates are capable of operating manual foot and hand controls. This study was done to determine current muscular strength and anthropometric characteristics of male and female aviation candidates. Volunteer subjects included 458 male and 152 female naval aviation students and Naval Academy Midshipmen. Cybex muscle testing equipment was used to measure the strength and endurance of muscles in the arm, shoulder, and leg. Fourteen different anthropometric measurements were made. Compared to males entering naval aviation, female candidates were weaker than their male counterparts when measuring both upper and lower body limb strength. Anthropometry indicated obvious differences in body size with men generally larger than women in most measurements. The data obtained in this study can be used to develop occupational strength standards for modern aviation, modify aircraft cockpits, and redesign aviation life support equipment. These results may help the Navy in preparing candidates for aviation and foster confidence in the assignment of aircraft.

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